

Finescale Structure of the Temperature-Salinity Relationship

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LONG-TERM GOALS

The long term goal of this project is to understand the processes that establish the temperature-salinity relationship in the ocean, with emphasis on the interplay between advection at the large scale, eddy stirring at the mesoscale and turbulent mixing at the finescale.

OBJECTIVES

The objectives of this proposal are (1) to unfold the processes that participate in the creation of the temperature-salinity relationship in two high-resolution data sets, the North Atlantic Tracer Release Experiment (NATRE) and the Salt Finger Tracer Release Experiment (SFTRE), and (2) to determine the relative importance of eddy stirring and turbulent mixing process in the ocean interior with a combination of numerical and theoretical tools.

APPROACH

The approach is foremost to analyze and interpret finescale phenomena in high-resolution oceanographic data sets, and secondarily to develop simple analytic and numerical representations to explain those phenomena. The work is done in collaboration by Raffaele Ferrari, at the Massachusetts Institute of Technology, and by Kurt Polzin, at the Woods Hole Oceanographic Institution. Shafer Smith, at the New York University, has developed the code to run high-resolution numerical experiments on a Beowulf cluster at MIT. Maxim Nikurachine, a student of the Joint Program between Woods Hole and MIT, helped with the analysis of the observations.

WORK COMPLETED

Ferrari completed the analysis of the temperature variance and eddy kinetic energy budgets for the NATRE data set. The analysis was based on an extension of the Oborn-Cox model to account for the production of finescale temperature variance by mesoscale eddies. The results are reported in a

manuscript submitted for publication to Deep Sea Research, a peer-reviewed journal. Polzin completed the processing of the SFTRE data set, resulting in estimates of all conventional microstructure quantities: vertical profiles of temperature, salinity, shear, thermal dissipation, and kinetic energy dissipation. These data will be analyzed with the same approach used for the NATRE data set. The quasi-geostrophic model written by Shafer Smith has been modified to run on the Beowulf cluster at MIT.

RESULTS

The Osborn-Cox model is a simplified temperature variance budget that is the basis for direct estimates of diapycnal diffusivities in the ocean. The model assumes that dissipation of thermal variance is due to turbulent motions acting on the mean temperature stratification. The model assumes the following path for temperature variance,

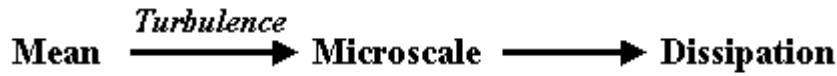


Figure 1. The Osborn-Cox model.

We extended the Osborn-Cox model to include the variance production by lateral stirring due to mesoscale eddy motions, using a triple decomposition scheme proposed by Russ Davis and Chris Garrett. The revised model shows that variance at the microscale can be generated by eddy stirring acting on the mean T-S profiles, creating finestructure, which is eventually removed by turbulence,

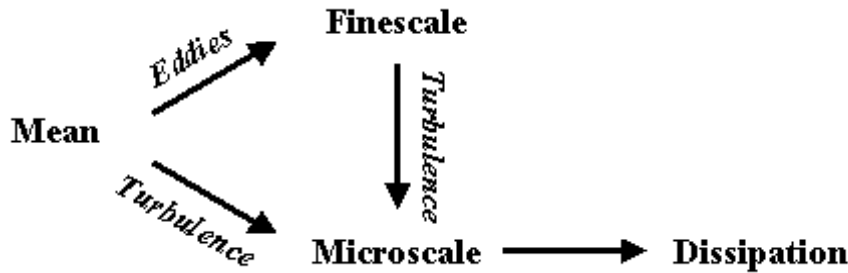


Figure 2. Revised Osborn-Cox model.

Turbulence and mesoscale eddies act very differently on temperature (T) and salinity (S) distributions. First, turbulence is characterized by motions with scales of O(1-10) m, while mesoscale motions span O(10-100) km. Second, turbulence drives fluxes both along and across density surfaces, while mesoscale eddy motions are directed along density surfaces (isopycnals). In regions where temperature variance production is dominated by turbulence, one expects to find smooth T-S profiles with wiggles at small scales. In regions where temperature variance production is dominated by eddy stirring, one expects T-S profiles to exhibit structure at the finescale along isopycnals. This paradigm was used to analyze microstructure measurements from the North Atlantic Tracer Release Experiment (NATRE).

The T-S relationship at the Mediterranean Water levels (about 1000 m depth) exhibits a large degree of variability along isopycnals. This finestructure is characterized by a lack of horizontal coherence: it is

difficult to relate features in one T-S profile with features in a neighboring profile a few kilometers apart. This lack of coherence is evident as a 0.2~psu cloud when T-S diagrams for nearby stations are overplotted (Figure 3). In contrast, at shallower levels characterized by North Atlantic Central Water, the T-S relationship is much tighter. The large amount of T-S variability at the Mediterranean Water level and the lack of horizontal coherence are consistent with T-S finestructure being generated by mesoscale stirring. The eddy field generates temperature variance by stirring the large-scale isopycnal gradients of temperature and salinity associated with the Mediterranean Tongue. The isopycnal gradients are much weaker at North Atlantic Central Water levels, and mesoscale stirring cannot generate finestructure.

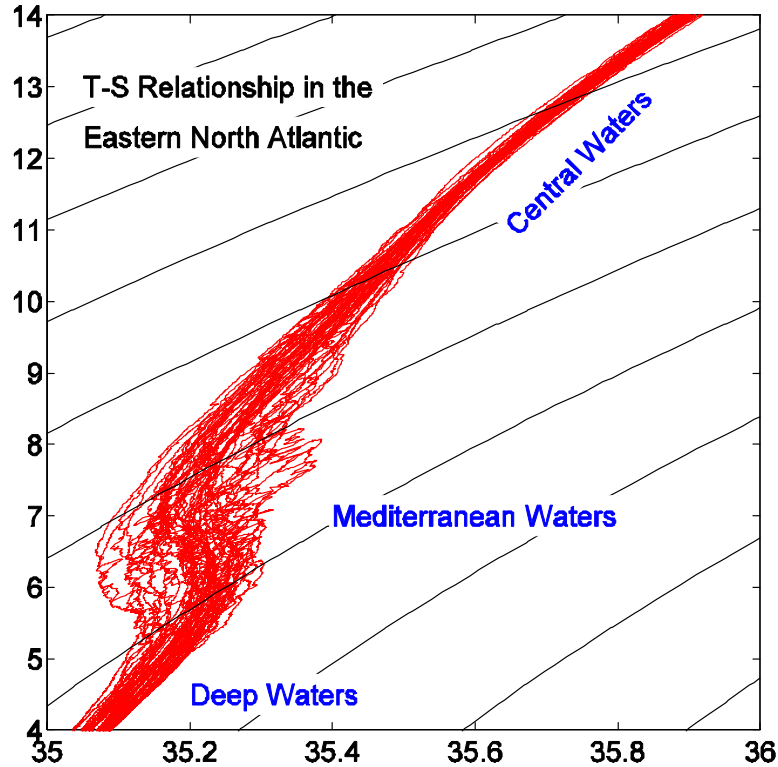


Figure 3. The T-S relationship in NATRE.

This interpretation of eddy stirring producing finestructure along isopycnals is supported by the temperature variance budget analysis of the NATRE data set. The analysis is based on the Osborn-Cox model modified to account for lateral eddy stirring (Figure 4). The budgets are computed for neutral layers approximately 100 m thick. The mean depths of the neutral surfaces (close to isopycnals) are used as the reference vertical coordinate. Microstructure estimates of temperature variance dissipation for each layer are shown in red and the shaded boxes represent the error bars. The production of variance by turbulent motions acting on the mean diapycnal gradient is shown in black. The production of variance by eddy stirring of the mean isopycnal gradient is represented in blue. At the North Atlantic Central Water level, temperature variance is associated with turbulence (i.e. internal wave breaking and double diffusion) acting on the mean diapycnal temperature gradient. At the Mediterranean Water level, eddy stirring dominates to the production of temperature gradient variance.

Preliminary analysis of microstructure data from the Salt Finger Tracer Release Experiment suggests that mesoscale eddy stirring plays an important role also in the Western North Atlantic.

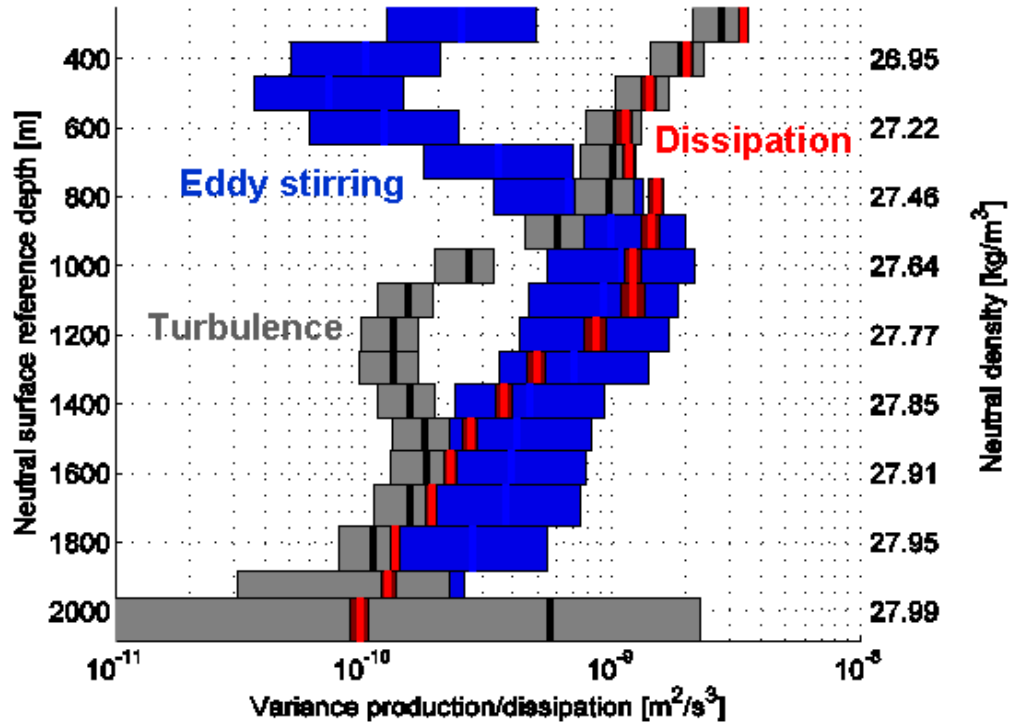


Figure 4. Temperature variance budget in NATRE.

A main result of this analysis is that eddy stirring contributes substantially to the generation of temperature variance at the microscale across water mass fronts, where there are T-S gradients along isopycnals. The resulting finestructure is characterized by compensating T-S gradients, i.e. T-S gradients with no signature on density. Some microscale mixing mechanism must occur to prevent the gradients from increasing without limit. Microstructure data suggest that, as the compensated gradients develop, they become unstable to double diffusive instabilities which limit the further growth of the gradients. This process produces extra diapycnal mixing that would not have occurred in the absence of lateral stirring. In this scenario eddy stirring controls the rate of double-diffusive turbulence, and hence of diapycnal mixing. This contrasts with the traditional interpretation that the rate of diapycnal mixing in regions characterized by water mass contrasts along isopycnals is set by double diffusion acting on the mean profiles.

The result of this analysis is relevant to the study of propagation of acoustic signals in the oceanic environment. Acoustic scattering is a product of sound speed anomalies associated with T-S finestructure and is extremely sensitive to the spectral distribution of such finestructure. In this work we have shown that eddy stirring sets the rate of creation of finestructure, while double diffusive instabilities control the spatial scales at which finestructure is dissipated. Thus parameterization of mesoscale processes together with parameterizations for double diffusion can be combined to predict the spectral distribution of finescale structure.

IMPACT/APPLICATIONS

We anticipate that this work will form the basis for future interpretation of microstructure data and for the parameterization of the interplay of mesoscale eddy stirring and double diffusive turbulence.

TRANSITIONS

Ocean circulation models are extremely sensitive to the rate of diapycnal mixing. Our work has shown that finescale structure can trigger double diffusive instabilities and hence diapycnal mixing. Thus the predictive ability of ocean models depends upon the parameterization of finestructure phenomena. The descriptions of finestructure and physical understanding provided by our simple analysis will help improve their skill.

RELATED PROJECTS

J. Ledwell, J. Toole and R. Schmitt were leading PIs in the NATRE and SFTRE experiments. The insight gained as part of this grant will have a direct impact on the interpretation and comparison of microstructure data and tracer release measurements.

PUBLICATIONS

Polzin, K. L, and R. Ferrari, 2003: Isopycnal Dispersion in NATRE, *Journal of Physical Oceanography*. [in press, refereed].

R. Ferrari, and K. L. Polzin, 2003: Temperature and Salinity Finestructure in NATRE, *Deep Sea Research*. [submitted, refereed].

HONORS/AWARDS/PRIZES

Raffaele Ferrari, Massachusetts Institute of Technology, Victor P. Starr Career Development Professorship, Massachusetts Institute of Technology.